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THE GLACIAL SUCCESSION IN NORWAY.

As SCANDINAVIA was unquestionably the chief center of the great North European glaciation, it follows that Norway is a country of glacial denudation rather than of glacial deposition. A complete apprehension of its Quaternary history is, therefore, not possible solely through the study of the deposits. The great marks of erosion are to be taken into consideration. We thus come immediately upon the great problem: How far are we to go in our acceptance of glacial erosion? It is of course impossible here to enter into the whole vexed question. It is, however, necessary to briefly summarize some of the reasons which lead the geologist in Norway to admit an erosion of so great degree, that both our fjords and lakes fall wholly within its limits. The most convincing argument is, perhaps, the fact that the great North European diluvial plain contains Scandinavian detritus in such immense quantity that the rock basins in Scandinavia could be refilled and replenished many times with it. A. Helland has calculated that the German and Russian diluvial sheet could fill not only the Scandinavian lakes, but also the Baltic, and still heighten the whole peninsula 25 metres (80'). And besides, we have the enormous quantity of Norwegian rock detritus which forms the bottom of the North Sea and the broad submarine plateau to the west of northern Norway. Even if this estimate is not entirely correct, it is impossible to deny that such enormous quantities of drift have been removed from Norway in Quaternary time that we must look for marks of denudation of quite as great degree as our lakes and fjords.

An estimate of the volume of rock matter which is carried by the glacial rivers of Greenland and Norway proves also that the glacier denudation in a few thousand years must reach great dimensions.

When thus the capacity of the rock basins comes short of holding the known glacial sediment (the quantitative element), the form of the basins (the qualitative element) is quite in harmony with those we find in other glaciated countries and *nowhere else*. Both the lakes and the fjords have a distinguishing trough shape, with flat bottoms and comparatively steep sides, in the transverse section, and, in the longitudinal section, a gradual deepening toward a point that is situated not very far from the outer end, against which it more suddenly shoals up. This form cannot be generated by any other possible eroding agent than glacier ice. The fissure theory is out of the question, as exact sections specifically show. Faults and dislocations cannot account for their specific form and their relations to quite superficial topographical features. The admirable monograph on the Kristiania fjord, by Professor W. C. Brögger, makes it also quite clear that its distinguishing fjord character can only be of glacial origin. Basins of this form, as is well known, are restricted to glaciated countries; and they can be deduced directly from the motion of the eroding glacier. The movement must accelerate towards the point where the ice surface intersects the snow line, where the surplus ice from the whole glacier must pass. Thence it must slacken because of the melting farther down. The erosion, which naturally must depend both on the movement and the pressure of the ice, will decrease accordingly. In this we find the explanation both of the longitudinal form of the glacial basins, and of their evident dependence on the margin of the land ice.

So much may be said about glacial erosion by way of introduction before entering into the study of the succession of glacial events in Norway. We must be somewhat prepared to face the greatness of the phenomena, which only glacial studies can make more familiar to us.

When we try to realize the appearance of Norway in *pre-*

glacial time,—*i. e.*, before the Quaternary age—we have not much on which to base our ideas. The immense denudation has so thoroughly altered the physiognomy of the country that we are quite at a loss to reconstruct it. We can only suppose that no great change in the relative heights of the mountain plateaus has taken place and that there are left, perhaps, in the mountain bosses remnants of the original surface. The coast line we are no doubt justified in putting farther outwards than now. The great slope to the ocean deep does not follow the present coast, but is up to 200 kilometers distant, the intervening bank not reaching beyond 400 meters. The flora and fauna of Spitzbergen and Iceland must have immigrated across this now sunken north-western foreland. Near Storeggen (about 62°) G. O. Sars found, by dredging at 100 to 200 fathoms (200 to 400M.), remains of a littoral fauna and beach shingle, which can only belong to a preglacial coast. It must therefore be a legitimate inference that the country in late preglacial times was, at least at the coast, 200 to 400 meters higher than now.

On the mountains in this high country there now began to gather great snow masses, the climate deteriorating owing to causes that cannot be treated here.¹ The névés gradually coalesced and the glaciers flowed down to the lower land. If the present numerous fjords had a preglacial existence they must have represented themselves as a close series of deep lakes or fjords into which the glacier soon crept. But beyond such a row of ready outlets no continuous ice margin could possibly grow. The depth of Sognefjord is 1,250 meters, of Hardangerfjord 800 meters, though both are rather shallow at their mouth. If the whole country was elevated 200 to 400 meters, we still would have so deep waters, that any glacier, which could not at once move forward with a thickness of 1,000 meters, would get afloat and be dissolved into icebergs as fast as it could grow. So any advance of inland ice (which necessarily increases but slowly) must

¹I have given my reasons for accepting a shifting of the pole as cause of the ice ages in a paper: *Strandlinje-studier* in *Archiv for Mathematik og Naturvidenskab* Kristiania, 1890-91, T. 9-10.

needs be impossible farther out than at the innermost fjord heads. The greatest distance between the heads of any two neighboring fjords on the whole Norwegian coast is only about 60 kilometers (less than 40 miles), and an ice stream driven out over this neck between Sognefjord and Nordfjord could not by any means reach a height of 510 meters at the isles in the mouth of Sognefjord, where we find glacial grooves and foreign boulders 1,760 meters, 5,700 feet above the fjord bottom. With only 20 to 30 kilometers to discharging outlets on each side, its thickness would ever be small. The fact must be kept in view that the inland ice behind, from which the ice stream flowed, had only a very inconsiderable breadth. The distance from the fjord heads to the present watershed is nowhere more than 30 kilometers, and the want of boulders transported from the country more to the east proves that the ice-shed, the glacial divide at the glacial period, could not have been situated far from the watershed. Now a névé less than 30 kilometers broad could never have pushed a continuous margin beyond a close set row of deep fjords. As we now in southern Norway actually find the whole west coast, except the highest points, very strongly glaciated, we are forced to admit that the only state of things in which the ice could have advanced so far west is to be found in a country where depressions, of a volume in any degree comparable with the present fjord system, are wanting. We are obliged to ascribe the formation of our fjords to Quaternary forces—that is, glacial erosion.

We know that boulders from the Kristiania fjord are found in the till as far away as North Netherlands and at Holderness, in England. We further know that the east-going ice flow in Scotland was turned back in Sutherland and that Orkney and Shetland were glaciated from the east, *i. e.*, from Norway. A continuous inland ice could not have grown gradually across the deep Norwegian channel, which encircles southern Norway, the deep sea basin reaching 900 meters. As in the case of the fjords, we must also conclude that this fjord-like basin (which indeed does not reach the depth of some of the fjords) did not exist in preglacial times, but owes its origin to the ice stream that flowed

outwards in it, following the line of least resistance for the ice overflow in central Scandinavia. This only need be 1,500 meters thick to be able to erode the bottom when the maximum erosion was in progress. This ice stream turned round the Naze and left its bottom moraine also on the southwestern Norwegian coastland, *e. g.*, on Jaederen, where boulders from the Kristiania territory are very numerous.

While the extreme eastern margin of the first great inland ice, as demonstrated by the extension of the boulder clay, reached to Kiew and Petschora, we must thus place the western margin at the steep slope to the Norway deep in the North Atlantic Ocean. But we have reason to think that it did not remain there for a very long time. As the weight of the ice increased the land was obliged to *sink* below it. This follows not only from the general physics of the earth's crust as demonstrated by O. Fisher, but can also be directly deduced from facts observed in all former glaciated countries. Invariably when there comes an inland ice there follows a depression; with the melting of it there is everywhere a re-upheaval; and everywhere the amplitude of the crust motion is in close accord with the thickness of the ice sheet.¹ Under the great first inland ice, Norway sank and therewith came a raising of the snow line in relation to the ice surface and an aggression on the ice from the rising sea. Under these circumstances the ice margin was forced back, and many things indicate that it at length took up its position at about the present coast line and paused there while the great terminal glaciers flowed down preglacial depressions and made new ones and scooped out, by long continued action, our grand fjords. Judging from their form and great dimensions, this erosion took place under very constant circumstances. The ice must have kept its place for a very long period constituting, in all probability, the greater part of the first great ice age. It might be objected that when the ice receded by the sinking of the land, the crust upheaval must have followed immediately. As the sea with its

¹ This I have followed out from the known glaciated countries in my Strandlinjestudier, but cannot in this place re-state it more fully.

greater specific gravity in a great degree replaced the melting ice margin, the consequence appears to have been that the land finally lost in height perhaps as much as 200 to 400 meters. We shall find analogous phenomena in other glaciated countries.

The thickness of the inland ice in Norway at this time we are able to estimate by the upper limit of foreign boulders and by the lower limit of the rocks on mountain summits which were not reached by the ice sheet. Where a great continuous scoring ice sheet has worked we find in Norway, as in Greenland and elsewhere, the smooth undulating surface lines with fresh rock surfaces. Higher up, above the reach of ice, we find the *numatak* formation with peaks and cirques (botner) and with highly weathered rocks and mighty talus and other debris. By such limits we can approximately determine that the maximum height of the ice sheet in southern Norway was below 2000 meters, in northern Norway about 1200 to 1500 meters, these being reckoned from the present sea level. As the mean height of the Norwegian highland may be estimated at 800 to 1000 meters, and as only central Norway reaches more than 1200 meters, we get an ice sheet which, near its axis, will measure only about 800 to 1000 meters. To this thickness of the ice the depression of the land answers very well according to O. Fisher's theory.

The first great Quaternary glaciation of Norway was followed by other great climatic changes. To get a more handy terminology than the common periphrastic nomenclature, I have proposed, for the most pronounced periods, the names *proteroglacial* for the earlier great ice age as distinguished from the well-known last great glaciation that followed—the *deutero-glacial*. I have chosen and press for acceptance at the Congress terms implying the first and the second of *two* periods because these two glaciations seem to be demonstrable for all glaciated countries. The names cannot well be misunderstood, and if, perchance, as some American and German geologists assume, a third separate glaciation can be proved, it will be easy to give it a name apart. So far we can only distinguish in Norway preglacial, proteroglacial,

interglacial, deuteroglacial, and postglacial periods, all very clearly denoted by these names.

The proteroglacial period came at last to an end. The ice retired very much; an interglacial period followed. Of this warmer period we know very few certain traces in Norway. Almost every deposit referable to it has been swept out by the last—the deuteroglacial—ice sheet at least in the parts best studied. At Jaederen we certainly have some layers of gravel and sand between the undermost bottom moraine carrying boulders from the Kristiania territory, and the uppermost one bearing boulders from the mountains close by on the east, but these layers do not contain, as far as known, any fossils giving information about the climate, and it may very probably be that they must be referred to the retiring proteroglacial or the advancing deuteroglacial ice.

The part of the proteroglacial country which was not covered by the deuteroglacial ice sheet or sea—and which, therefore, might have retained interglacial deposits—is very poor in loose matter and it has, as yet, not been possible to distinguish any interglacial debris. In the center of the country at Våge, near the highest mountains in Norway, there was some years ago found in river gravel a molar of the mammoth. It may now be said, that this tooth is certainly neither postglacial, protero- nor deuteroglacial, as the tract in these periods was quite ice-covered. There remains the assumption that it is preglacial or interglacial, and as it is not very probable that this molar has remained unmolested through the very long first glaciation by which the whole country was deeply eroded, it is perhaps permissible to take it for interglacial. In this case we may conclude that the country in interglacial time was covered with forest up to the highest plateaus; and, therefore, the *proteroglacial inland ice was entirely gone*.

It is, however, more reliable to seek for support by a comparison with neighboring countries. The peats in parts of Denmark not deuteroglaciated show an arctic flora with *Dryas*, *Salix polaris*, *herbacea*, and *reticulata*, which followed the great retreating proteroglacial ice sheet, and this was superseded by a vegetation char-

acterized by *Populus tremula*, and this again by a *Pinus sylvestris* flora.

Above the layer with *Pinus* comes a new one with oak and finally the surface stratum with recent forest trees. Now, in the peats of deuteroglaciated Norway and Sweden we always find the oak layer on the bottom (with a layer of pine and birch above), which shows, without doubt, that the preceding vegetations in Denmark and Scania must be interglacial. To judge from the aspen and pine forests it might be concluded that the interglacial climate in Scandinavia was somewhat colder than the present, but the melting of the ice may have required a higher temperature and the fossils from layers between the two bottom moraines in the Baltic countries bear a rather southern stamp.

We come to more reliable ground when we advance to the last great glaciation in the *deuteroglacial period*. Again the snow gathered on the high mountain plateaus, again glaciers pushed forward towards the lower ground accompanied by a severe climate. But the glaciers this time were met almost at the watershed by the deep proteroglacial fjords which necessarily must put an end to their advance westward. The continuous western ice margin could not reach beyond the fjord heads. To the east, however, the way was free for the growing inland ice. The consequence of this was that the *ice sheet* divide crept eastwards and reached a line up to 130 kilometers southeast of the land watershed. Here at last the resistance to the glacier motion was alike on both sides of it. *We therefore find the boulders in deuteroglacial time*—in contrast to the distribution in proteroglacial time—*transported across the watershed from lower ground in southeastern central parts* up hundreds of meters to the divide and borne on as far west as the deuteroglacial ice and its icebergs went.

To the west we find the ice margin determined by the fjords, to the east it pushed forward out to the coast line by Skagerak. We find its margin, as in the case of the deuteroglacial ice in North America, marked by a long terminal moraine—*raerne*—from Arendal to the Kristiania fjord and thence to southeastern Sweden.

Also in Finland we find a terminal moraine near the south coast. But through this terminal moraine there crept out a very long Baltic ice tongue which reached down to Brandenburg and the eastern part of Schleswic. Behind the terminal moraine in Norway we find a series of lakes eroded, here as elsewhere, near the ice margin, but these lakes are rather small and have no relation to the present valleys behind. It is therefore reasonable to suppose that the inland ice did not have any very considerable thickness here when it reached this extreme limit and also that the valleys were not yet fully developed.

As in proteroglacial time, the country again sank under the ice weight and again the ice sheet retreated with the relative raising of the snowline, and advance of the sea. The retreat is near Kristiania fjord marked by three or four discontinuous moraine lines with, in places, rather large lakes behind (Oiern, Tyrifjord, Norsjö). But in Norway—as in America—a final position was not reached before the great marginal glacier was settled in what was to become a fine row of great lake basins: Solör (filled up), Mjösen, Randsfjord, Sperillen, Kröderen, etc. This most constant phase of the deuteroglacial time deserves a particular name. I have called it the *Epiglacial* epoch, as it closes the great glacial series. It is parallel to the American Champlain epoch, but as American geologists (Dana especially) regard the Champlain epoch as postglacial, I have not ventured to accept the name.

In southeastern Norway we find the terminal glaciers ending in the greatest lake basins in the country; in western and northern Norway the glaciers were, as above explained, stopped by the fjord heads. But here we also find that the glacier ends everywhere once occupied smaller but yet deep lakes, with bottoms often below the sea level, just behind the fjord heads. When we in Norway have more than 100 such lakes cut in the rock just where the glaciers terminated, I cannot see how it is possible to evade the conclusion that these lakes must be of glacial origin. It will not do to suppose that this coincidence of so many lakes and glacier ends is the merest accident. The relation must needs be genetic. The form of the lakes is the typical trough with a longi-

tudinal section in the best accordance with the probable distribution of the erosive power in a glacier.

The rock matter which was scooped out by the epiglacial glaciers was deposited partially as terminal moraines, but mostly as terraces in the fjords. We therefore now find the epiglacial lakes everywhere separated from the fjord heads by some kilometers of terrace land. These great upper terraces mark the level of the epiglacial sea. Their height differs very much in the different districts, and it was first by the study of the corresponding ancient sea beaches that I was able to find the correlation between them. In western and northern Norway, these ancient sea margins are very distinctly marked, often in the living rock. As might be expected, in accordance with the theory of isostasy of the earth's crust, these lines are now raised towards the former center of the ice sheet, from which the maximum ice load was taken away. Nearest this point the epiglacial sea beach and terraces now reach 200 meters above the sea, with a gradual fall towards the outer coast, where their height is only some 20 meters or less. The gradient in the fall is much greater than in Lake Agassiz, reaching 1.2 meters (4') per kilometer, against 0.10 meters (20"), but it is clearly the same cause that has been at work in both cases.

The height of the deuteroglacial ice sheets seems to have been almost the same as in the proteroglacial—less than 2,000 meters maximum above the present sea level.

The epiglacial terraces contain in some places banks of shells with quite an arctic aspect. The deeper clay has *Leda artica* as its leading fossil. The climate must have been very like that at present in South Greenland, and the topographical physiognomy must also have been very much the same, with a partially alpine foreland (which constituted nunatak forms as in the proteroglacial epoch), and with glaciers at the heads of the fjords, with great clay bars or deltas before them, and with small floating icebergs to score out the strandlinjer—the sea beaches in the rock.

It is altogether probable that a meteorological map of Nor-

way in epiglacial time was very like a modern map of Greenland. The isotherm of $0^{\circ}\text{C}.$ for the year must have followed the southern coast perhaps as far up as to the polar circle. The lower isotherms must have enclosed a pronounced minimum to the east of the ice shed, where certainly $-20^{\circ}\text{C}.$ must have reigned.¹ While the difference from the present mean temperature at the coast was only 5 to $6^{\circ}\text{C}.$, the difference near the pole of maximum cold must have been $15^{\circ}\text{C}.$ at least. This great difference, which is a necessary consequence of the contrast between coast climate and the pronounced continental climate over the east side of the great ice field, is as yet not sufficiently noted by the students of glacial time. An exact consideration of the distribution of the meteorological elements above the inland ices will give the solution of many glacial problems. I shall here only remark that the snowfall in this continental region must have been almost imperceptible as in winter in Siberia now—and likewise the melting. Now, the power which keeps the glacier in motion is ever the surplus of snowfall. The whole continental side of the inland ice must thus be kept in quite a passive motion, be pushed as a rather thin ice plate out to the margin by the press from the greater snowfall on inside ice nearer the ice shed and the coast. The reliable measures of the ice sheet in the Baltic show really very small dimensions—less than 200 meters—thus it will become intelligible why the greater ice masses to the west can keep the ice divide four to six times nearer the western margin. An ice plate of about 100 meters or less must be impotent to erode. The bottom moraine from the more powerful inner part must be gradually built up *below* the outer thin marginal ice sheet. On the continental side we will have formed a regular boulder-clay or thick bottom moraine outside an area where denudation in the form of broad shallow basins or plains will still take place—all this against the deep rock basins with terminal moraines and terraces before them, on the coast side. The snowfall here will be very great. The surplus ice

¹ Cf. H. MOHN's meteorological map of Greenland in *Wissenschaftliche Ergebnisse, von Dr. NANSEN'S, Durchquerung von Groenland*, Gotha, 1892.

will be carried with considerable speed by steep glaciers to the sea; the localized erosion will be very energetic; and we will get the fiords and the lakes—while the eroded matter will only be deposited *before* the glaciers as terminal moraines and terraces.

As the ice shed will be rather near the coastward margin of the inland ice, it follows that it is for a great part the enormous snowfall on the great western glacier's own surface which is to be transported. Hence these glaciers can follow more irregular lines from the first, only deepening and widening the preëxisting valleys, and so we get the complicated fjord systems; while, on the continental side, where a more uniform *vis a tergo* pushes the ice plate forward, the eroded depressions must be more regular. It is quite necessary to keep in view this great contrast between erosion and deposition on the part of the continental and the coast sides of the great ice sheets, respectively, in order to be able to understand many of the complicated glacial phenomena.

We have seen that the deuteroglacial and especially the epiglacial inland ice had its ice shed far to the east from the watershed. Across this divide the ice must move and with somewhat accelerated speed in the narrow defiles. There must here originate passes or gaps (*skar* in Norwegian) across the watershed. Of these, we really have very many in Norway with a development in distinct relation to the distance between the ice-shed and the watershed and to the greatness of the epiglacial lakes and valleys on both sides. In not a few we have lakes with outlets on either side.

When the ice stream through such a gap came out to the western edge of the high plateau, there resulted a sort of ice cascade, which, like a waterfall, receded with rather great speed. These receding icefalls evidently gave origin to most of our *fjord-valleys*, *sack-valleys*, *culs de sac* interior to the fjord heads. Also these must generally be of deuteroglacial origin, as only then the ice flowed in great streams across the watershed.

The epiglacial stage of the deuteroglacial period must have had a very abrupt termination. The glaciers retired from the

epiglacial lakes without filling them up in any considerable degree. The ice melted so speedily away, and the crust swelled up so fast, that the deposits of the rivers just below the epiglacial terrace level are very small. This could only occur with a climate more genial than the present in which an existing glacier as great as the epiglacial land ice would certainly assert itself with success.

We must suppose a considerable uplift of the snow line in this time which followed the epiglacial period, and which I shall call the *Boreal period*. Such a genial climate in early post-glacial time we are forced to assume also on biological reasons. On the warm valley sides in the western interior fjords, we find many plants which can only prosper in a temperature more than 2°C . higher than now prevails in the intervening tract across which they must necessarily have immigrated. On the southwestern coast flourished a vegetation almost like the Irish coast flora, but separated from its main habitat by a temperature perhaps 4°C . lower in January than it will bear. These Boreal and Atlantic plants can only have spread to their isolated places in Norway in a climate some 3°C . warmer than the present. That this warmer time did occur in early post-glacial time is again proved by the stratification in the peats, where the plants most susceptible of cold (ash, oak, etc.) are found in the deepest layer or rather on the bottom itself—this also in places on the coast and in the mountains where now no forest tree grows.

These $3\text{--}4^{\circ}\text{C}$. recorded by the vegetation would certainly have raised the snow line, which now is 1200 to 1800 meters above the sea in Norway, above almost the whole epiglacial ice sheet, which nowhere attained 2000 meters. The great inland ice must then have become a *dead* glacier, and must have melted rapidly, especially from the margins. The last remnants of it might be supposed to have been situated near its maximum elevation, *i. e.*, near the ice shed. This lay, as explained above, in deuteroglacial time at some distance to the southeast of the land watershed, as the many boulders in the upper eastern valleys which were transported upwards prove. The ice remnant is then to be

sought for as far as 100 kilometers to the east and south of the watershed. This southern position was moreover accentuated by meteorological facts. The western moist winds are intercepted by the broad western alpine foreland and the high land near the watershed, while the low country at the southeast would give the moist winds free access to the southern glacier side. The country close to the watershed on the southeast now gets almost all its humidity from the southeast winds, but these would, in early post-glacial time, be barred by the inland ice, which in this way would come to have a very dry north side, in contrast to a very moist south side. This would draw the last inland ice out to the southeast edge of the mountain plateau to a point not far above the great epiglacial lakes in southern Norway.

But the melting of the inland ice did not go on uninterruptedly. When the land had risen more than half the post-glacial uplift, and when, presumably, the ice was more than half gone, a new deterioration of the climate commenced. It is possible it did not get worse than the present, but it was enough to stop the melting of the inland ice, which again arose above the snow line. The ice again assumed the character of a living glacier, and kept its position unaltered for a long time. Under the pressure of this constant ice load the land again was kept at a constant level. We find, especially in northern Norway, a new strandlinje (sea beach), occurring at about 40 per cent. of the epiglacial and great terraces, built up with a fauna quite like the modern. This new marked phase in postglacial time I have called *the sub-glacial period*, denoting its half glacial condition. In Sweden this epoch is also marked by a very distinct beach line, but in Scania and Gothland this low raised beach in places is built upon peat, which shows that the uplift of land in the Boreal period did exceed that in the following. For this reason, the Swedish geologists speak of the *post-glacial depression*. The term post-glacial for this general phase is very unfortunate. It must necessarily literally denote all the time after the deuteroglacial-epiglacial period, for which time we have no other name. And as the constant level in Norway only represents a single phase in the

general post-glacial upheaval, and as the depression in southern Sweden may be a quite local, peripheric phenomenon attached to the Baltic, I must insist upon the more significant, yet neutral, form *subglacial* period for the age of the lower beach line.

The inland ice was then, as explained, reduced to a zone (about 50 kilometers broad) across the middle of the eastern valleys. This fact must have a curious consequence in the fact that these valleys must have been dammed up by the ice and filled with lakes whose outlets ran west and north through the gaps in the watershed. These glacial lakes have actually left very distinct marks in the greatest eastern valleys in Norway, Gudbrandsdal and Oesterdal. We not only find in their upper tracts enormous terraces of material brought by the glacier from the south, terraces without any parallel on the other side of the watershed, but we also find here very fine beach lines—*seter*—partially cut in the rock, corresponding in height with the terraces and with the draining gaps, 620^m, 660^m respectively—quite like the famous Parallel roads of Lochaber, but very much more extensive. From these ice-dammed subglacial lakes there flowed great rivers across the present watershed filling up with their heavy sediment many of the epiglacial lakes on the northwestern coast, and building great subglacial clay terraces at the level of the lower ancient sea beach.

The erosion of the marginal glaciers has set its mark also in the subglacial time in some inland lakes as Storsjö and Sensjö, in Oesterdalen, Mösvatn and Totak, in Telemarken which have their greatest depth in the upper part and terminal moraines at the present upper end of the lakes.

So far as I can see the subglacial period also prevailed in North America, without receiving yet, however, due attention from glacial students. I cannot here deal with all the raised beaches in the east formed by the sea and by the lakes which naturally can be referred to this period, but I shall use the occasion to point out that the apparently insoluble difficulty in harmonizing archeological and biological facts with the geological data connected with the ancient "Quaternary" lakes in the Great Basin

will immediately vanish when the two great humid periods are regarded not as proteroglacial and as deuteroglacial, but as deuteroglacial and subglacial or—what I think is more probable—as correlate with the two Norwegian post-glacial warm periods (before and after the subglacial), the climatic changes caused by a shifting of the pole westwards, which alone is able to account for the late glaciation of the Cordilleras in Atlantic post-glacial.

At last also the subglacial remainder of the inland ice commenced to melt away in the warm subboreal period. The country rose farther above the sea, and finally, by some intermediate steps, attained its present position. The modern sea beach shows everywhere so great a development, and is so sharply built, that all alleged displacement in historical times must be received with the greatest distrust. We have, notwithstanding all such relations, full reason to maintain that the seashore since the ice left has remained practically unchanged, as also the climate in historical time. We have reached the constant *recent period* in the most rigorous sense, and therewith conclude our synopsis of the Quaternary history of Norway.

There is, however, yet a problem of capital interest, which I cannot quite pass even in this short account. It is the question, When did *man* appear in geological history? The evidence given in Norway is, however, not very direct. We have seen that all traces of preglacial life were swept away, except the littoral find at great depth at Storeggen. We have also seen that the traces of interglacial life are very doubtful, and that we were obliged to go to Denmark to get better information about interglacial time. We have found that the Arctic flora here (with the reindeer) which flourished upon the proteroglacial bottom moraine, was superseded by the aspen vegetation (with elk) when the reindeer had already disappeared (J. Steenstrup). Now we know that in central Europe paleolithic man was contemporaneous with the reindeer, which will date this reindeer period back to the close of the proteroglacial time, and probably yet higher up. But in Denmark, it is only with the next vegetation, with *Pinus sylvestris*, that the first traces of man

appear, represented by the well-known refuse heaps, the *kökken möddinger*, where, with shells and bones of *Bos primigenius* and *Alca impennis*, are found many rude instruments of horn, bone, or stone. This culture, which did not know any other domesticated animal than the dog, is by some archeologists called mesolithic. *Kökken möddinger* and implements of the same type, the *coast finds*, are only discovered in non-deutero-glaciated places of Denmark and Sweden, which fact alone goes far to prove the assumption that the *Pinus sylvestris* period really is interglacial, as I have advocated above. And the molluscs in the refuse heaps on the northern shores of the Danish isles are quite the same as in the (upper) *Cyprina*-clay on the southern shores, which overlies the proteroglacial moraine, and is here generally ploughed out by the rather feeble margin of the deutero-glacial Baltic ice tongue. This interglacial layer contains often a stratum with fresh water molluscs and in this supramarine deposit there was found in Langeland shells of *Cardium edule* and *Nassa reticulata*, in which I cannot but see a rudimentary *kökken mödding* and a proof for the interglacial age of this mesolithic culture.

From Norway we have only a few finds of implements of this type, as might be expected, because the habitable coast was so greatly depressed and covered in the following deutero-glacial period. But it is reasonable to suppose that it also was inhabited by a population akin to the Danish. When the latest ice sheet pushed forward to the great mostly-submarine terminal moraine, the retreat of this population on the western foreland was intercepted, and interglacial man was obliged to adjust his mode of life somehow to Esquimaux fashion. But there is no reason to think him quite exterminated here on the shore of the life-giving Atlantic. And anthropologic studies have indeed proved that on the western margin, just so far east as the deutero-glacial ice left land outside, there lives yet a brachycephalic population, while everywhere else (even in the innermost western fjords) dolichocephals and mesocephals are in great majority. This distribution of anthropological types is quite unaccountable by any other supposition than that the brachycephals are descend-

ants of the interglacial Norwegians and that the whole deutero-glaciated country was peopled by Aryan dolichocephals in early post-glacial, boreal time. We know that these new immigrants had at least four domesticated animals, and were in possession of the art of grinding their stone implements. Can we now date the appearance of *neolithic man* by more direct geological means? There are found so many flint implements in such depth in probable subglacial terraces in Norway that it may be taken for granted that the country was populated, however sparsely, up to and beyond the polar circle in subglacial time. In Sweden polished implements have been discovered in the peat layers below the subglacial beach, so it will perhaps be reasonable to refer the first appearance of neolithic man also on geological dates to the genial Boreal period between epiglacial and subglacial time. Approaching our own culture, we find that the country in the *bronze age* was still depressed. In Smålenene, to the east of Kristianiafjord, are observed about 150 rock sculptures from the bronze age which are situated at about 22 to 25 meters above the sea; none at lower levels. As these sculptures almost always are made along a shore, we are justified in supposing that more than ten per cent. of the land yet was unfinished in early bronze age. From early *iron age* we have barrows quite near the present constant sea level, so we may assume that the recent geological period coincides with the iron age and historical time.

If the theory of ice depression is correct, there must, even in the bronze age, have existed a remnant of the inland ice, which, as explained before, must be sought for across the middle of eastern valleys. In this zone we could not expect to find implements from the stone age or bronze age. There has as yet been found only four stone hatchets in all the districts near the former ice shed, against many hundred stone implements in the districts on both sides of the same valleys, and these perforated hatchets have been in use far down in metallic time.

The ice zone must have stopped the immigration as the inland ice of Greenland does now. This is the reason together with the

depression of the coast land why neolithic man did not go farther up in Sweden than 61° northeast, while the Norwegian coast was free all along, and permitted his advance up to 70° . Another consequence is that the northern part of the long valleys in southeastern Norway must get its first population from the west coast. This is also proved to be the case, not only by the existence of a well-marked anthropological boundary across these continuous valleys, but also by a singular contrast in dialects and traditions. Reversedly, this signifies that the present Scandinavian race really was the first post-glacial occupant of the country. In the administrative divisions we find traces of the old ice barrier as far down as only a century ago. It is thus possible to follow the effect of the ancient land ice in Norway down to our own day.

In closing this hasty summary of the Quaternary history of Norway I cannot quite omit the doubtful question about the absolute chronology. We have seen that in the bronze age which the archeologists are able to date in Scandinavia from 1700 to 500 B.C., more than ten per cent. of the post-glacial upheaval was not yet accomplished. As the upheaval has not been uninterrupted, we cannot directly conclude that the whole elevation has had a duration of about 30,000 years. The long time from early iron age in which the shore line has been constant enters into our standard. But we can draw a more reliable comparison between the terraces from the different periods, when we take the greater eroding power of the old inland ice and its greater glaciers in due consideration. I cannot here specify my calculations, but will say that I regard myself as on the safe side when I compute the time for forming the subglacial terraces and beaches to not more than double the last constant period, which may be reckoned at 2,000 years. For these two constant post-glacial periods together we thus get about 5,000 to 6,000 years. The relatively small terrace deposits from the remainder of post-glacial time cannot by any means give more than half this value. We may, therefore, on this, as I think, very reliable estimate, calculate the whole post-glacial time to be 7,000 to 9,000 years. To about the same numbers

I have come by calculating from the mean depth of neolithic finds in Norwegian peats, but this computation has not quite so much importance, though the fact that the generally adopted archeological chronology agrees as well with geological estimates certainly has some weight.

I shall recall the fact that calculations on the length of post-glacial time based on the receding Niagara, St. Anthony Falls, or the Michigan lake shore, on boulder pedestals in Scotland, the denudation of the Somme, the Plum creek, or the Raccoon valley, deposition of the Tinière or the Rhone, etc., delta, the thickness of glacial clay in New Hampshire and in Sweden, the rate of growth of peat in North America and Ireland, the atmospheric waste of the Parallel roads in Lochaber, the depth of some ancient neolithic finds, that all these give numbers of about the same value, 5,000 to 12,000 years. Doubtful as some of these chronometers may be, all fair chances are against any supposition which differs in any considerable degree from those of about *thirty independent* estimates I have got together. With full regard to a legitimate calculation of probabilities, it may be predicated that the number of 7,000 to 10,000 years is as nearly an exact estimate of the *duration of post-glacial time* as can ever be expected.

It is now tempting to try a comparison between the subglacial and the epiglacial terraces and lakes in Norway. When the much greater eroding force of the epiglacial glaciers is properly reduced, I do not think it can be very much at variance with the truth to compute the epiglacial period to be between five and ten times the duration of the subglacial, the smaller number being somewhat more probable. We would then get *10,000 to 20,000 years for the epiglacial period and perhaps 15,000 to 25,000 for the whole deuteroglacial time*. For the *interglacial period*, the Norwegian geology cannot as yet give any reliable measure but the depth of the aspen and pine layers in the Danish peats as compared with the post-glacial oak and birch layers does answer very well to the American estimates of one and one-half to two times the duration of post-glacial time—let us take about 15,000 years. We may next compare the proteroglacial fjords with the epiglacial lakes

and may by these means get some idea as to the length of the first great ice age. The farther we go from our own time the more wholly conjectural will our numbers become, of course. But as other more reliable measures as yet are wanting, I shall venture a first approximation, calculating the time in which the enormous proteroglacial marginal glaciers eroded our fjords, as five to ten times the epiglacial time in which our great epiglacial lakes were scooped out—the higher estimate in this case being somewhat more probable. This would perhaps make *100,000 to 150,000 years for the whole proteroglacial period, i. e.*, about five times the duration of the deuteroglacial time—a relation which, as far as I see, is in very good accordance with the general quantitative difference between the effects of the first and second great glaciations. This will give for the whole Quaternary-post-tertiary time about 140,000–200,000 years.

I see very well how precarious such computations may seem, especially as I here cannot give the detailed calculations—but I do not think it possible that any of these have given numbers five times too great or small. Under these circumstances they must be taken for a very good geological approximation. By getting parallel estimates from other glaciated countries, it will appear, I think, that we will have, on wholly geological ground, more positive and reliable data for the Quaternary chronology, than those derived from astronomical speculations.

I add for greater ease in comparison my reading of the Quaternary history of Norway in a tabular form.

ANDR. M. HANSEN.

SYNOPSIS OF QUATERNARY HISTORY OF NORWAY.

Period.	Epoch.	Ice Sheet.	Elevation of Land.	Erosion.	Deposits.	Temperature.	Fauna and Flora.	Man.	Probable Duration (1000 yrs).
Protero-glacial.	1.	1. Grows to the ocean slope. 2. Terminal glaciers in the fiords, eastern margin near Petschora.	Sinks from 2-400 M. above the present to about the present (?)	1 & 2. Norwegian channel. 2. The great fiords.	Undermost bottom moraine on continental side. Terrace plain sub-marine around the west coast.	Sinking from the warmer Pleistocene to 8-10° C. below the present mean.	Arctic.	No traces.	100-150
	2.								
Interglacial.	1.	None (?)	The present (?)	The present forces.	Intermediate sand layers at Jaederen (?)	At times warmer than now.	1. { Reindeer 2. { Dryas 3. { Elk. Populus trem. Bos primig. Pinus sylv.	3. Danish køkken moddinger. Western brachyceph. in Norway.	15-20
	2.								
Deutero-glacial.	1. Ra-Epoch.	1. Grows to the fiord heads, terminal moraine Baltic tongue. 2. Terminal glaciers in the lakes behind the fiord heads.	1. Sinking to about 250 M. below the present near the ice centre. 2. Upper ancient beach.	1. Ra-lakes and intermediate lakes behind the moraines. 2. Great lakes near the fiords. Gaps at the watershed. Sack valleys.	1. Terminal moraine. Upper alluvium round the Baltic. 2. High marine terraces.	2.5-5° C. lower than the present.	2. Arctic (Leda clay).	?	2. 10-15-20-25.
	2. Epi-glacial.								
Postglacial.	1. Boreal.	1. Melting rapidly.	1. Rising rapidly.	1. Rivercuts in epiglacial terraces.	1. Small terraces.	1. About 3° C. warmer.	1. Boreal (oak, ash).	1. Neolithic immigration.	7-9.
	2. Sub-glacial.	2. Gone except across the eastern valleys.	2. At the lower (40 pct.) ancient beach.	2. Lakes in central Norway. Seter.	2. Terraces at 40 pct.; inland terraces.	2. As now.	2. As now.	2. Neolithic man.	
	3. Sub-boreal.	3. Melting away.	3. Rising to the present.	3. As now.	3. Small terraces.	3. Somewhat higher.	3. Some southern forms. Pine in the peats.	3. Bronze age at 10 pct. of the upheaval.	
	4. Recent.	4. Gone.	4. The present.	4. The present.	4. The present.	4. The present.	4. The present.	4. Iron age, historical time.	

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NAES. HEDEM. AUGUST, 1893.